Comprehensive assessment of debris in the Karakoram Mountain ranges of northern Pakistan using geospatial tools and field data

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Debris flows are among mountainous regions' most destructive natural hazards, causing frequent and significant physical, environmental, and economic damage. The spatial and temporal dynamics and magnitude of debris flow are influenced by climate, geology, topography, hydrology, interconnected sediment sources, and human activity. Northern Pakistan is particularly susceptible to debris flows due to its active tectonic, steep terrain, fragile landscape, and climate. The frequency of these events has increased in recent years due to climate change, posing a major challenge to the sustainable development of the vulnerable mountain communities. Therefore, it is crucial to identify potential debris flow hazard zones and assess their impacts on downstream infrastructure and communities to support evidence-based risk mitigation and adaptation strategies. This research presents a systematic approach for debris flow hazard assessment at the catchment scale, integrating the evaluation of downstream infrastructure, environmental, and social vulnerabilities in District Ghizer. The methodology employs open-source remote sensing datasets, extensive field observations, and statistical modeling techniques to enhance hazard characterization and risk assessment. Digital Elevation Model (DEM) and satellite images-derived morphometric parameters, hydrological settings, and land cover were analyzed using a multi-criteria decision support system to evaluate the susceptibility of catchments to debris flow. The hazard assessment results concluded the prone catchments to debris flows. The study evaluates the potential impacts of debris flow on the elements at risk situated on the respective alluvial fans, including buildings, roads, population, forest, and agricultural land. In this study, the vulnerability of elements exposed to debris flows has been evaluated by analyzing their type, quantity, spatial distribution, economic significance, and structural fragility. The delineated catchments and evaluated risks in the study are vital for local communities and organizations in formulating mitigation strategies for adapting to evolving risk to debris flows driven by climate change.

Keywords: Debris flow; Catchment; Hazard; vulnerability; risk; north Pakistan; Remote sensing